Geographic variation in the leaf essential oils of *Juniperus grandis* (Cupressaceae) III. San Gabriel Mtns. population.

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ABSTRACT

Analysis of the volatile leaf oil of *J. grandis* from the San Gabriel Mtns. is presented along with analysis of trees from the San Bernardino Mtns. and the High Sierra, CA. The oil of *J. grandis*, San Gabriel Mtns., is dominated by sabinene (14.8%), δ-3-carene (13.4%) and α-pinene (10.6%) with moderate amounts of α-terpinene (4.9%), limonene (2.8%), β-phellandrene (4.2%), γ-terpinene (4.6%), terpinolene (3.8%), terpinen-4-ol (4.6%), bornyl acetate (1.5%), methyl geranate (1.6%), δ-cadinene (1.9%), elemicin (1.2%) and germacren-D-4-ol (1.6%). Its oil is very similar to that from the San Bernardino Mtns. The oils from San Gabriel and San Bernardino Mtns. were intermediate between *J. grandis* (High Sierra) and *J. osteosperma* (NV), suggesting the trees may be of hybrid origin. Published on-line **www.phytologia.org** *Phytologia 97(2): 94-102 (April 1, 2015).* ISSN 030319430.

KEY WORDS: *Juniperus grandis (= J. occidentalis* var. *australis), J. occidentalis, J. osteosperma,* Cupressaceae, essential oils, terpenes, geographic variation.

Previously, Adams (2012) and Adams and Kauffmann (2010a) reported on geographic variation in the leaf essential oils of *J. grandis* R. P. Adams (= *J. occidentalis* var. *australis* (Vasek) A. & N. Holmgren). They found that the leaf oils of *J. grandis* contained two chemical races: High Sierra populations with oils dominated by δ-3-carene (17.9-30.0%) and low in sabinene, and the San Bernardino Mtns. population with oil low in δ-3-carene, but very high in sabinene (24.3%). In addition, they found the leaf oil of putative '*J. grandis*' of the Yolla Bolly Mtns. to be more similar to the oil of *J. occidentalis* than to that of *J. grandis*. Subsequent DNA sequencing gave support that the Yolla Bolly Mtns. juniper is a divergent form of *J. occidentalis* (Adams and Kauffmann, 2010b; Adams, 2014).

Adams (2012) analyzed the leaf oils of additional populations from Beckwourth and Stampede Meadows, CA. He found the oils from Stampede Meadows to be like those of *J. grandis* (Fig. 1), but the Beckwourth trees appear to be hybrids between *J. grandis* and *J. occidentalis* (Fig. 1).

The overall trend in the leaf oils of *J. grandis* shows the highest similarity of oils is in the High Sierra (Meyers and Sonora Junction) followed by Donner Pass, Stampede Meadows and the 9 Mile locality (Fig. 2). The San Bernardino Mtns. oils are much less similar and is actually more like the Yolla Bolly (*J. occidentalis*) oils than the nearby 9 Mile population.

In the present study, we report on the oil from a disjunct population of *J. grandis* from the San Gabriel Mtns., CA.

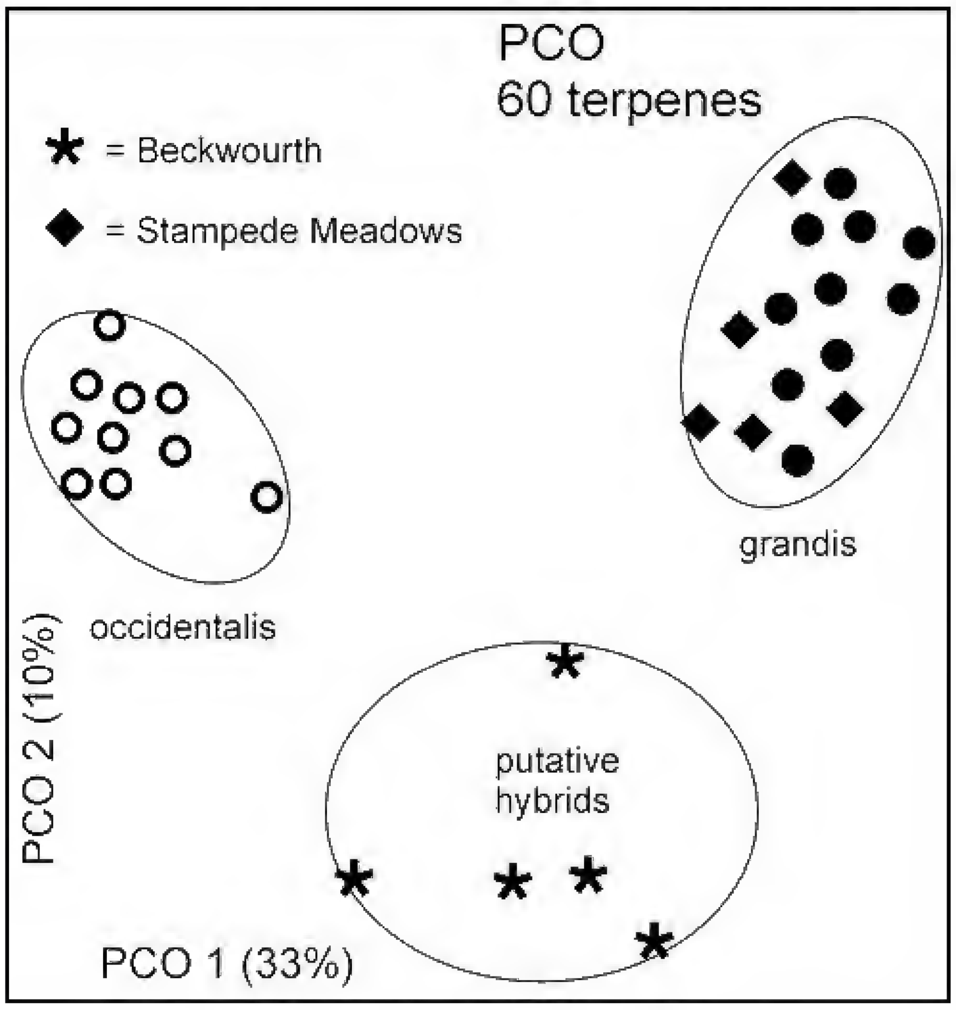

Figure 1. PCO based on 60 terpenes, ordinating *J. grandis, J. occidentalis* and putative hybrids from Beckwourth. From Adams (2012).

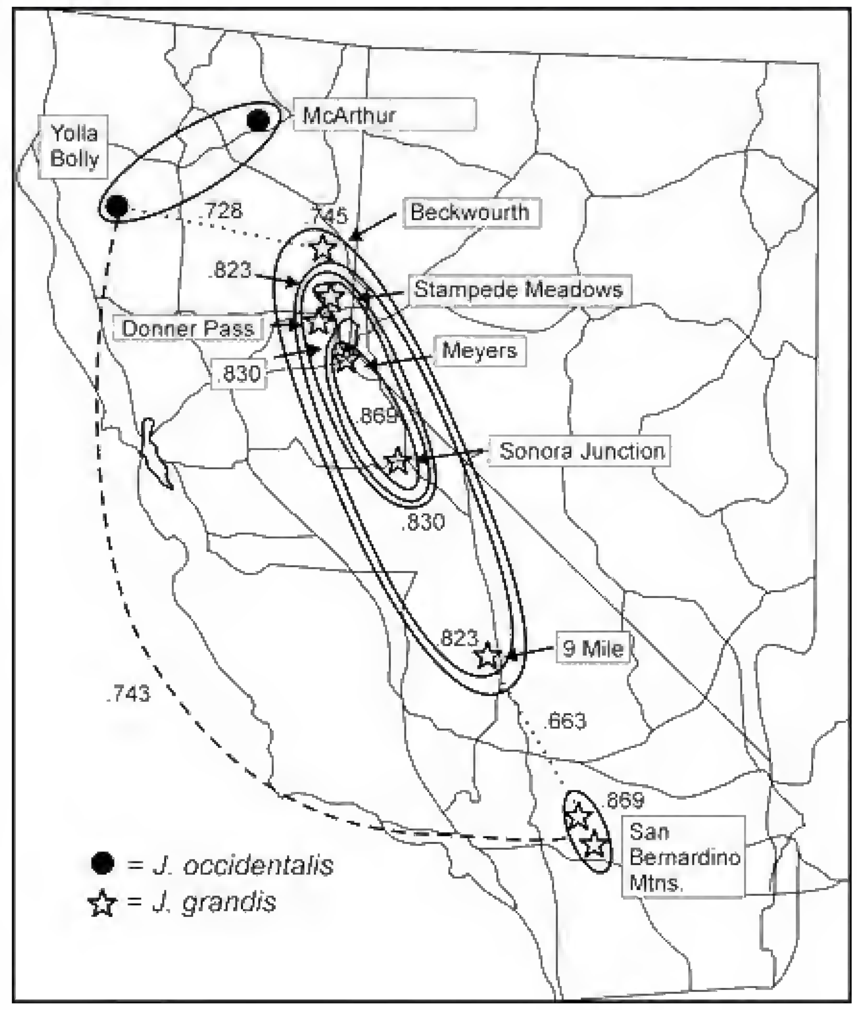

Figure 2. Contoured clustering based on *63* terpenoids. The dashed and dotted lines show unusual links. The numbers next the lines are the similarities. From Adams (2012).

MATERIALS AND METHODS

Plant material (see also Fig. 3): *J. grandis, Adams 11963-11967*, Jct. US 50 & CA 89, 38° 51.086N, 120° 01.244'W, 1937 m, Meyers, El Dorado Co.; CA; *Adams 11968-11972*, 16 km w of Sonora Jct., on CA Hwy. 108, 38° 18.289'N, 111° 35.598'W, 2585 m, Tuolumne Co.; CA, *Adams 11984-11988*, Nine Mile Canyon Rd., 20 km w of Jct. with US 395, 35° 54.003'N, 118° 02.078'W, 2059 m, Tulare Co., CA; *Adams 11989-11993*, 5km n Big Bear City on CA 18, 34° 17.533'N, 116° 49.153'W, 2053 m, San Bernardino Co., CA; *J. grandis, Adams 11963-11967*, Jct. US 50 & CA 89, 38° 51.086N, 120° 01.244'W, 1937 m, Meyers, El Dorado Co.; CA; *Adams 11968-11972*, 16 km w of Sonora Jct., on CA Hwy. 108, 38° 18.289'N, 111° 35.598'W, 2585 m, Tuolumne Co.; CA, *Adams 11984-11988*, Nine Mile Canyon Rd., 20 km w of Jct. with US 395, 35° 54.003'N, 118° 02.078'W, 2059 m, Tulare Co., CA; *Adams 11989-11993*, 5km n Big Bear City on CA 18, 34° 17.533'N, 116° 49.153'W, 2053 m, San Bernardino Co., CA; *Adams 12319-12322,* Onyx Summit on CA 38, 34° 11.524'N; 116° 43.227' W.2600 m, San Bernardino Co., CA; *Adams 12328-12331, 12367,* Donner Pass Summit on old US50, 39° 18.999' N; 120° 19.581' W. 2180 m, Placer Co., CA; *Adams 12332-12336,* on Stampede Meadows Rd. (Co. Rd 894 A1t), 5 mi. n of I80. 39° 24.966' N; 120° 05.249' W, 1660 m, Nevada Co., CA; *Adams 12337-12341,* 4.7 mi. n of Beckwourth on Beckwourth-Genesee Rd., 39°52.433'N; 120° 24.345'W, 1770 m, Plumas Co., CA; Lab acc. *Adams 13532-13536*, ex *Rick Riefner, Jr. 12-332, 12-335, 12-342-344*, clustered weathered trees on granitic rocks, uncommon, w of Mt. Baldy Notch on Devils Backbone Trail, San Gabriel Mtns., 6 - 7 m trees, multiple coalescing trunks, 34° 17' 9.595" N, 117° 37' 58.801"W, 2719-2891 m, 26 Aug 2012, Los Angeles Co., CA.

J. occidentalis, Adams 11940-11942, 12 km e of Jct. WA 14 & US 97 on WA 14, 45° 44.392'N, 120° 41.207'W, 170 m, Klickitat Co.; WA, *Adams 11943-11945,* 2 km s of Jct. US 97 & US 197 on US 97, 38

km ne of Madras, OR; 44° 53.676'N, 120° 56.131'W, 951 m, Wasco Co., OR; *Adams 11946-11948*, 3 km sw of Bend, OR; on OR 372, 44° 02.390'N, 121° 20.054'W, 1132 m, Deschutes Co., OR; *Adams 11949-11951,* 32 km e of Bend, OR on OR 20, shrubs, 0.5 - 1m tall, 43° 53.922'N, 120° 59.187'W, 1274 m, Deschutes Co., OR; *Adams 11952-11954,* 14 km e of Jct. OR66 & I5, on OR66, 42° 08.044'N, 122° 34.130'W, 701 m, Jackson Co., OR; *Adams 11957-11959*, on CA299, 10 km e of McArthur, CA, 41° 05.313'N, 121° 18.921'W, 1091 m, Lassen Co., CA; *Adams 11995-11998 (Kauffmann A1-A3, B1),* Yolla Bolly-Middle Eel Wilderness, 40° 06' 34"N, 122° 57' 59W, 1815- 2000 m, Trinity Co., CA, *Adams 12342-12346*, 19 km WSE of Susanville, CA, on CA 36, 40° 22.178'N, 120° 50.211' W, 1570 m, Lassen Co., CA, *Adams 12347-12351*, on US 395, 5 km n of Madeline, 41° 05.867'N, 120° 28.456' W, 1695 m, Lassen Co., CA.
J. osteosperma, Hancock Summit, mile 38 on US 375, 37° 26.404'N, 115° 22.703'W, 1675 m, Lincoln Co. NV; *Adams 11125-11127*, McKinney Tanks Summit on US 6, 38° 07.005'N, 116° 54.103'W, 1933 m, Nye Co., NV. Voucher specimens are deposited in the Herbarium, Baylor University (BAYLU).

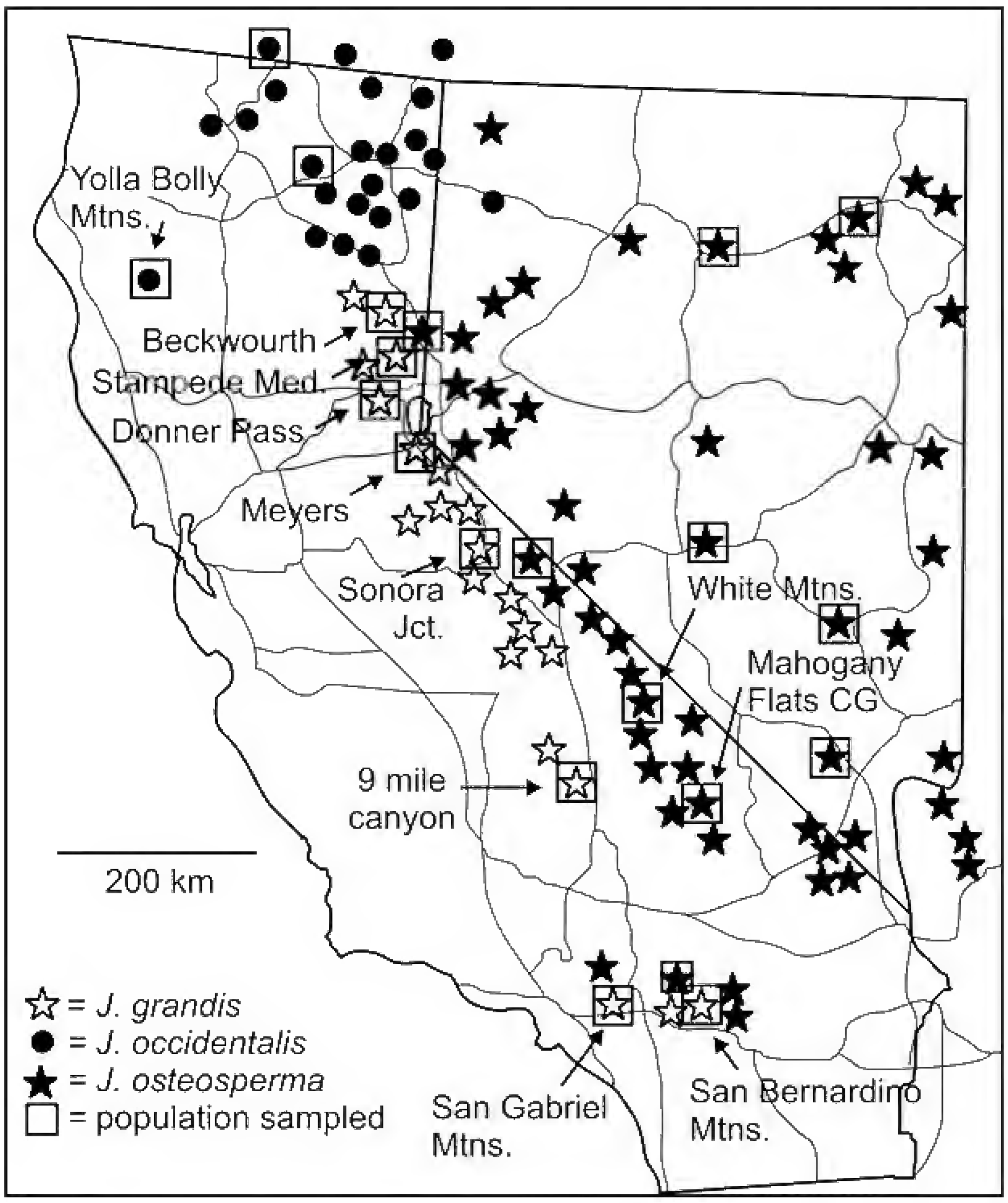

Figure 3. Distributions of *J. grandis*, *J. occidentalis* and *J. osteosperma*, modified from Vasek (1966) and Adams and Kaufmann (2010a). Note the San Gabriel Mtns., population; the focus of this study.

Fresh leaves (200 g) were steam distilled for 2 h using a circulatory Clevenger-type apparatus (Adams, 1991). The oil samples were concentrated (ether trap removed) with nitrogen and the samples stored at -20ºC until analyzed. The extracted leaves were oven dried (100ºC, 48 h) for determination of oil yields. Oils were analyzed and average values reported. The oils were analyzed on a HP5971 MSD mass spectrometer, scan time 1/ sec., directly coupled to a HP 5890 gas chromatograph, using a J & W DB-5, 0.26 mm x 30 m, 0.25 micron coating thickness, fused silica capillary column (see Adams, 2007 for operating details). Identifications were made by library searches of our volatile oil library (Adams, 2007), using the HP Chemstation library search routines, coupled with retention time data of authentic reference compounds. Quantitation was by FID on an HP 5890 gas chromatograph using a J & W DB-5, 0.26 mm x 30 m, 0.25 micron coating thickness, fused silica capillary column using the HP Chemstation software. Terpenoids (as per cent total oil) were coded and compared among the species by the Gower metric (1971). Principal coordinate analysis was performed by factoring the associational matrix using the formulation of Gower (1966) and Veldman (1967).

RESULTS AND DISCUSSION

The oil of *J. grandis*, San Gabriel Mtns., is dominated by sabinene (14.8%), δ-3-carene (13.4%) and α-pinene (10.6%) with moderate amounts of α-terpinene (4.9%), limonene (2.8%), β-phellandrene (4.2%), γ-terpinene (4.6%), terpinolene (3.8%), terpinen-4-ol (4.6%), bornyl acetate (1.5%), methyl geranate (1.6%), δ-cadinene (1.9%), elemicin (1.2%) and germacren-D-4-ol (1.6%). Its oil is very similar to that from the San Bernardino Mtns. (Table 1).

PCO (Principal Coordinates Ordination) based on 62 terpenes, using population averages resulted in three eigenroots before they appeared to asymptote accounting for 34.16%, 15.10% and 10.27% of the variation among OTUs. This ordination shows (Fig. 4) clear grouping of *J. osteosperma* (NV), *J. occidentalis* (n CA), *J. grandis* (High Sierra, CA), the Beckwourth population (*J. grandis* x occidentalis), and the southern *J. grandis* group (San Gabriel and San Bernardino Mtns.), which appear intermediate between *J. grandis* and *J. osteosperma* in the ordination (Fig. 4).

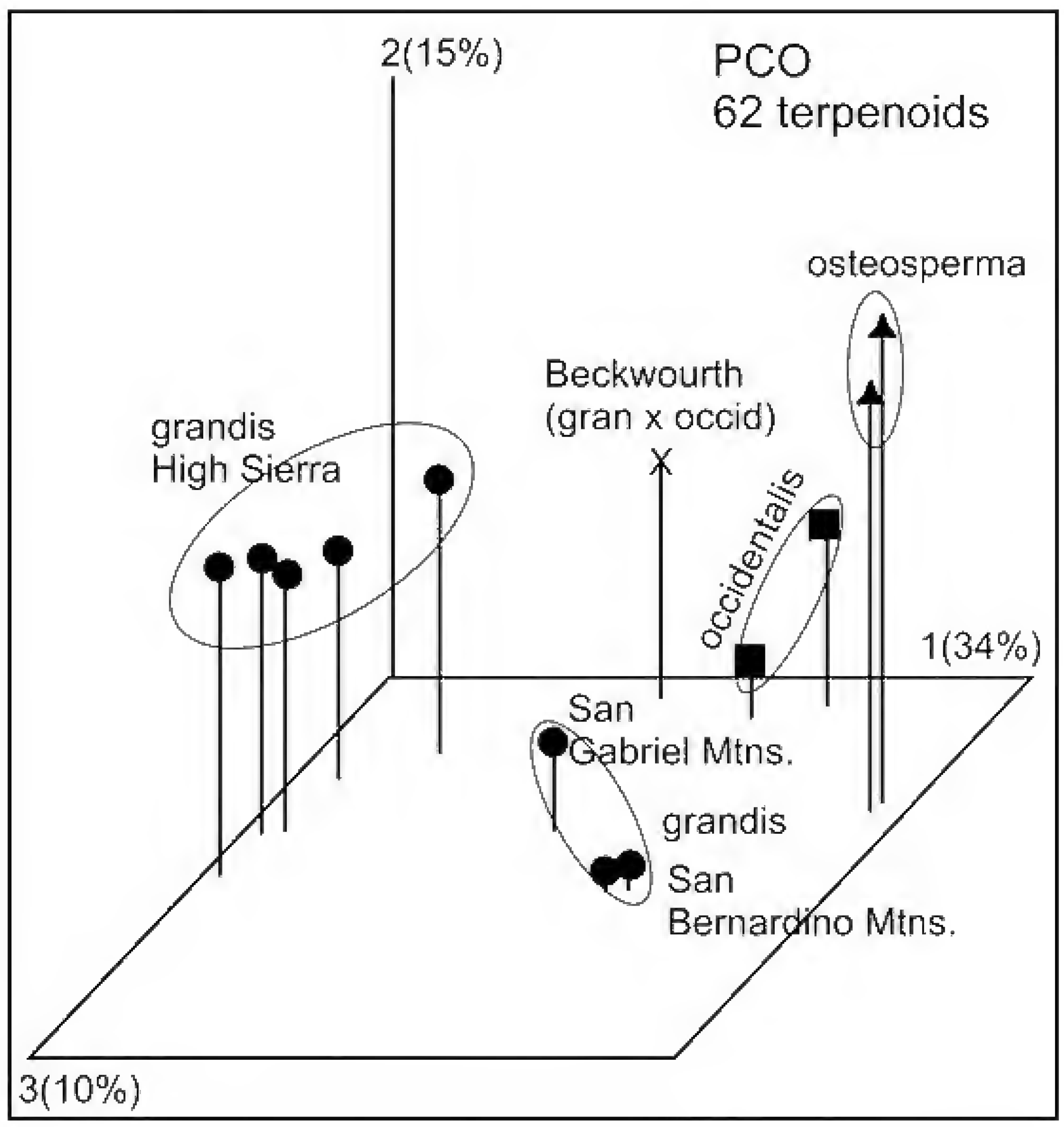

Figure 4. PCO based on 62 terpenoids, weights = 1. In this ordination, the San Gabriel and San Bernardino Mtns. populations appear to be intermediate in their oils.

To further examine the oils of *J. grandis,* individuals in southern California, ANOVA was performed between ten *J. grandis* oils from the High Sierra and ten *J. osteosperma* trees from Nevada. The resulting F ratios were used as character weights (F-1 weighting) for 40 terpenoids with the largest F values. Adams and Tsumura (2012) analyzed artificial hybrids between cultivars of

Cryptomeria japonica and found that F-1 weighting in PCO was the most effective method to discriminate between parents and hybrids. Later, Adams and Stoehr (2013) extended the study of the inheritance of terpenoids by examining *Pseudotsuga menziesii* F_1 hybrids (vars. *menziesii* X *glauca*). They found, again, that F-1 weighting in PCO was the most effective method to discriminate between parents and hybrids, confirming the earlier study by Adams (1982). PCO resulted in only 3 eigenroots that accounted 47%, 16% and 6% of the variation among OTUS. Figure 5 shows PCO between individuals from pure populations of *J. grandis* (High Sierra), *J. osteosperma* (Nevada) and individuals from the San Bernardino and San Gabriel Mtns. Notice that the reference individuals of *J. grandis* and *J. osteosperma* are in tight groups due to the F-1 weighting. The individuals from the San Bernardino and San Gabriel Mtns. are very loosely ordinated between *J. grandis* and *J. osteosperma.* There is some hint of differentiation between San Bernardino and San Gabriel Mtns. individuals (as indicated by the dashed line in Fig. 5).

The variation among the southern California *J. grandis* trees (Fig. 5) is seen in the composition in Table 2. Several compounds in trees are transgressive to the means (α-pinene, sabinene, δ-3-carene, α-terpinene, terpinen-4-ol, methyl geranate and elemicin) and exhibit extreme variation.

The loose grouping of the San Bernardino and San Gabriel Mtns. trees is suggestive of long term inter-crossing of hybrids and backcrosses, such that the populations are very diverse. It may be that if hybridization has occurred, it was during the Wisconsin glacial maximum when the ranges of *J. grandis* and *J. osteosperma* were highly overlapping. *Juniperus osteosperma* still grows at lower elevations in the basin below Big Bear Lake, while *J. grandis* grows at Big Bear and higher elevations, such that the taxa are scarcely, isolated. Alternatively, this may be a case of stabilized hybridization.

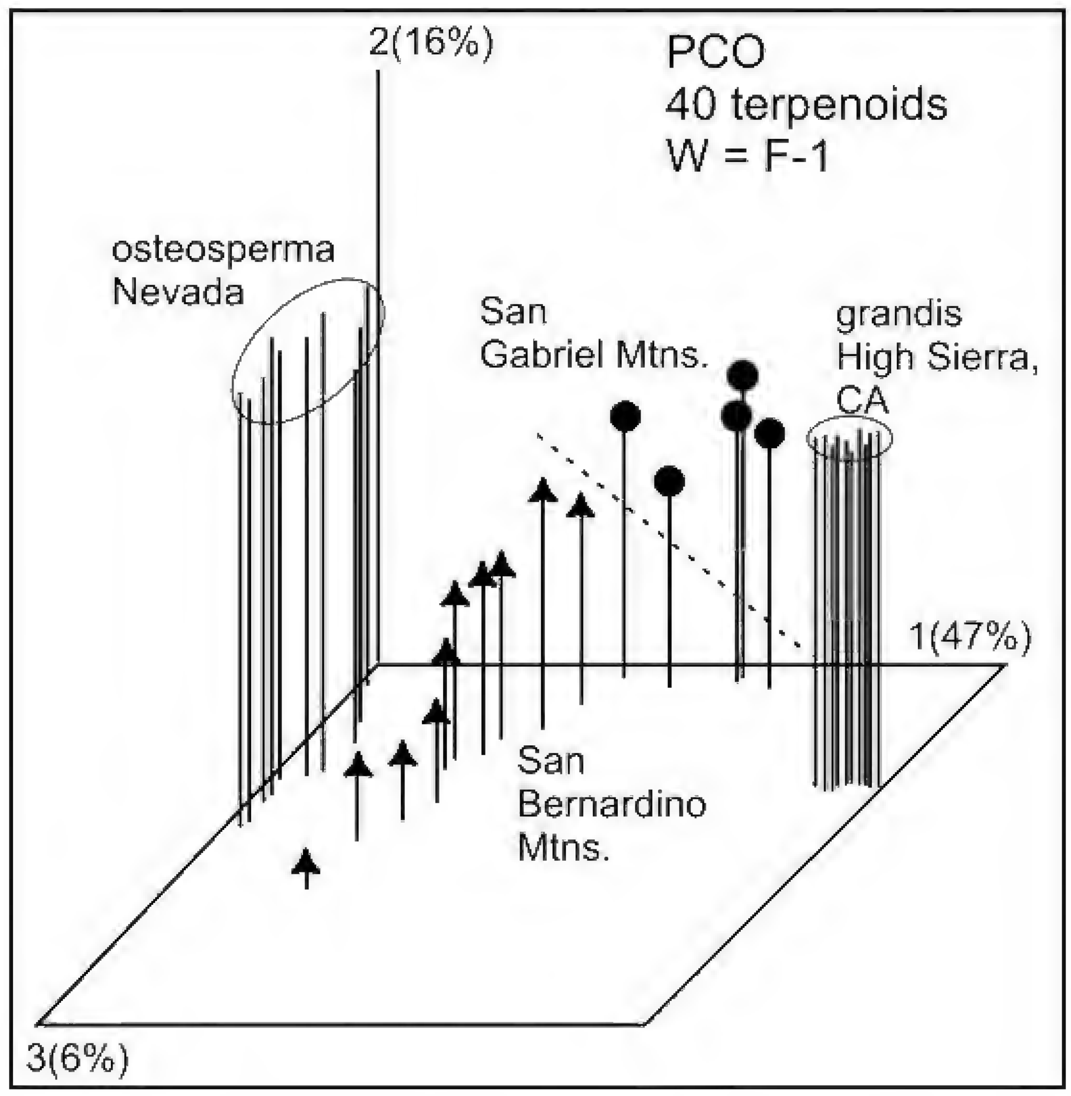

Figure 5. PCO based on 40, F-1 weighted terpenoids. The dashed line divides San Gabriel and San Bernardino Mtns. individuals.

It should also be noted that Adams and Kauffmann (2010b) found differences in trnS-trnG sequences between *J. grandis* (Meyers, CA, High Sierra) and *J. osteosperma* (Utah) but not between *J. grandis* (Big Bear, CA) and *J. osteosperma* (Utah). In addition, neither petN-psbM, nor trnD-trnT differed between *J. grandis* (Big Bear, CA) and *J. osteosperma* (Utah), suggestive that the *J. grandis* at Big Bear may contain the *J. osteosperma* cp genome. *Juniperus grandis* from both the San Bernardino and San Gabriel Mtns. have cinnamon colored bark and broad tapered trunks in older trees that are typical of *J. grandis* from the High Sierra. Additional research into the status of *J. grandis* in southern California is planned (RPA).

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LITERATURE CITED

Adams, R. P. 1982. A comparison of multivariate methods for the detection of hybridization. Taxon 31: 646-661.

Adams, R. P. 1991. Cedarwood oil - Analysis and properties. pp. 159-173. in: Modern Methods of Plant Analysis, New Series: Oil and Waxes. H.-F. Linskens and J. F. Jackson, eds. Springler- Verlag, Berlin.

Adams, R. P. 2007. Identification of essential oil components by gas chromatography/ mass spectrometry. 4th ed. Allured Publ., Carol Stream, IL.

Adams, R. P. 2012. Geographic variation in the leaf essential oils of *Juniperus grandis* (Cupressaceae) II. Phytologia 94: 3-21.

Adams, R. P. 2014. The junipers of the world: The genus *Juniperus*. 4th ed. Trafford Publ., Victoria, BC.

Adams, R. P. and M. E. Kauffmann. 2010a. Geographic variation in the leaf essential oils of *Juniperus grandis* and comparison with *J. occidentalis* and *J. osteosperma.* Phytologia 92: 167-185.

Adams, R. P. and M. E. Kauffmann. 2010b. Geographic variation in nrDNA and cp DNA of *Juniperus californica, J. grandis, J. occidentalis* and *J. osteosperma* (Cupressaceae). Phytologia 92: 266-276.

Adams, R. P. and M. Stoehr. 2013. Multivariate detection of hybridization using conifer terpenes II: Analyses of terpene inheritance patterns in *Pseudotsuga menziesii* F_1 hybrids. Phytologia 95: 42-57.

Adams, R. P. and Y. Tsumura. 2012. Multivariate detection of hybridization using conifer terpenes I: Analysis of terpene inheritance patterns in *Cryptomeria japonica* F_1 hybrids. Phytologia 94: 253-275.

Gower, J. C. 1966. Some distance properties of latent root and vector methods used in multivariate analysis. Biometrika 53: 326-338.

Gower, J. C. 1971. A general coefficient of similarity and some of its properties. Biometrics 27: 857-874

Vasek, F. C. 1966. The distribution and taxonomy of three western junipers. Brittonia 18: 350-372.

Veldman D. J. 1967. Fortran programming for the behavioral sciences. Holt, Rinehart and Winston Publ., NY.

Table 1. Leaf essential oil compositions for three populations of *J. grandis*, (Meyers, CA; Stampede Meadows, CA, Beckwourth, CA, Big Bear City, San Bernardino Mtns., CA and San Gabriel Mtns., CA) plus *J. osteosperma* (McKinney Tanks Summit, NV), and *J. occidentalis* (McArthur, CA). Compounds in boldface appear to separate taxa and were used in numerical analyses. KI = Kovats Index (linear) on DB-5 column. *Tentatively identified. Compositional values less than 0.1% are denoted as traces (t). Unidentified components less than 0.5% are not reported. Those compounds that appear to distinguish taxa are in boldface.

KI	Compound	grandis	grandis	grandis	grandis	grandis	osteo	occid
		San Gab	Big Bear	Meyers	Stamp	Beckw.	Nevada	McArt.
921	tricyclene	t	0.3	-	-	0.1	0.9	1.1
924	**α-thujene**	**0.8**	**2.3**	**-**	**-**	**0.4**	**0.5**	**1.0**
932	α-pinene	10.6	7.1	14.0	6.8	2.5	4.4	5.0
945	**α-fenchene**	**0.7**	**0.2**	**1.5**	**1.2**	**t**	**-**	**t**
946	camphene	0.8	0.3	-	-	0.3	1.1	1.0
953	thuja-2,4-diene	-	-	t	-	-	t	t
961	**verbenene**	**1.0**	**0.3**	**2.9**	**2.0**	**0.6**	**-**	**-**
969	**sabinene**	**14.8**	**24.3**	**-**	**t**	**10.7**	**10.2**	**12.0**
974	β-pinene	0.8	0.5	1.3	0.8	0.6	0.2	0.4
988	myrcene	0.6	1.7	3.1	3.4	3.5	1.7	1.3
1001	δ-2-carene	0.7	0.1	1.1	0.7	0.8	-	t
1002	α-phellandrene	1.2	0.4	1.6	1.6	4.0	0.3	0.8
1008	**δ-3-carene**	**13.4**	**2.8**	**27.3**	**17.0**	**1.6**	**-**	**1.0**
1014	α-terpinene	4.9	3.0	0.4	0.3	1.1	1.3	1.7
1020	p-cymene	1.7	6.5	1.4	0.2	2.0	2.4	10.7
1024	**limonene**	**2.8**	**1.6**	**1.2**	**t**	**t**	**2.1**	**0.9**
1025	**β-phellandrene**	**4.2**	**1.5**	**10.6**	**16.1**	**20.1**	**3.2**	**3.5**
1044	(E)-β-ocimene	t	0.3	t	t	0.2	t	0.1
1054	γ-terpinene	4.6	4.9	0.3	0.6	1.6	2.1	3.0
1065	**cis-sabinene hydrate**	**0.5**	**1.9**	**-**	**-**	**0.5**	**0.8**	**0.9**
1086	terpinolene	3.8	1.9	3.7	2.3	1.7	1.4	1.3
1092	96, 109,43,152, C10-OH	0.3	t	0.9	1.2	-	-	-
1095	**trans-sabinene hydrate**	**0.7**	**1.8**	**-**	**-**	**0.4**	**1.0**	**0.7**
1095	linalool	-	-	t	0.7	0.5	t	0.5
1100	55,83,110,156, unknown	-	-	-	-	-	-	0.3
1112	trans-thujone	t	0.2	-	-	-	-	t
1118	cis-p-menth-2-en-1-ol	0.7	0.7	0.8	1.7	2.7	0.6	0.7
1122	α-campholenal	-	-	t	-	-	0.3	-
1132	cis-limonene oxide (furanoid)	t	t	t	-	-	-	-
1136	trans-p-menth-2-en-1-ol	0.5	0.8	0.9	1.4	2.0	-	0.9
1141	**camphor**	**0.1**	**1.2**	**-**	**0.5**	**0.3**	**23.7**	**2.5**
1144	**neo-isopulegol**	**-**	**-**	**0.5**	**0.5**	**-**	**-**	**-**
1145	camphene hydrate	0.1	0.2	t	t	0.2	1.5	0.2
1154	**p-menth-1,5-dien-8-ol isomer**	**0.4**	**t**	**0.6**	**0.8**	**t**	**-**	**-**
1154	sabina ketone	t	0.9	-	-	t	0.8	0.4
1161	p-menth-1,5-dien-8-ol	0.4	t	0.3	-	-	-	-
1165	**borneol**	**t**	**0.1**	**-**	**-**	**-**	**6.0**	**2.2**
1166	coahuilensol	0.5	t	t	0.7	1.2	t	0.6
1174	**terpinen-4-ol**	**4.6**	**9.3**	**0.4**	**0.8**	**3.7**	**8.3**	**6.7**
1176	**m-cymen-9-ol**	**-**	**-**	**0.4**	**1.2**	**0.4**	**-**	**-**
1176	cryptone	-	-	-	-	t	-	-
1179	p-cymen-8-ol	0.2	1.0	0.4	1.1	0.2	0.5	0.5
1186	α-terpineol	0.4	0.3	1.2	0.3	-	0.4	0.4
1195	myrtenol	0.3	0.2	-	-	-	0.2	-
1195	cis-piperitol	0.3	0.2	0.4	0.6	0.6	0.3	0.2
1207	trans-piperitol	0.3	0.6	0.9	1.4	1.0	0.3	0.3
1219	coahuilensol, methyl ether	0.5	0.2	-	-	-	0.2	-

KI	Compound	grandis San Gab	grandis Big Bear	grandis Meyers	grandis Stamp	grandis Beckw.	osteo Nevada	occid McArt.
1223	**citronellol**	**0.6**	**0.2**	**t**	**0.4**	**0.4**	t	**8.4**
1230	**trans-chrysanthenyl acetate**	**0.7**	**0.4**	**3.9**	**3.2**	**0.5**	**-**	**-**
1238	cumin aldehyde	t	0.3	-	-	-	0.3	0.2
1239	carvone	-	-	t	0.3	-	0.6	-
1249	piperitone	0.6	t	1.2	2.0	0.9	t	0.2
1253	trans-sabinene hydrate acetate	t	0.6	-	-	-	-	-
1254	linalool acetate	-	-	-	-	-	-	0.1
1255	4Z-decenol	-	-	0.4	-	-	-	-
1257	methyl citronellate	0.5	0.1	0.2	0.2	-	-	-
1274	neo-isopulegyl acetate	-	-	0.3	0.2	-	-	-
1284	**bornyl acetate**	**1.5**	**2.2**	**0.4**	**0.8**	**5.2**	**16.6**	**9.5**
1285	**safrole**	**-**	**-**	**0.3**	**0.1**	**-**	t	**-**
1298	carvacrol	t	0.2	0.2	0.3	0.3	t	0.4
1298	3'-methoxy-acetophenone	0.4	0.2	-		-	-	-
1319	149,69,91,164, phenolic	-	-	0.8	-	-	-	-
1322	**methyl geranate**	**1.6**	**1.8**	**-**	**1.4**	**16.3**	-	**1.0**
1325	p-mentha-1,4-dien-7-ol	0.1	0.7	-	-	-	t	t
1332	cis-piperitol acetate	-	-	0.4	-	-	-	-
1343	trans-piperitol acetate	0.1	t	0.3	-	-	-	-
1345	α-cubebene	t	t	-	-	-	-	t
1374	α-copaene	0.1	0.2	-	-	t	-	1.0
1387	β-bourbonene	0.1	0.3	0.5	-	-	-	0.2
1388	**79,43,91,180, unknown**	**-**	**-**	**0.3**	**0.3**	**0.1**	**-**	**-**
1389	**111,81,151,182, unknown**	**0.5**	**0.4**	**1.0**	**1.2**	**0.2**	**-**	**-**
1403	methyl eugenol	-	-	t	0.2	-	-	-
1417	(E)-caryophyllene	t	0.2	-	-	-	-	-
1429	cis-thujopsene	-	-	-	-	-	-	0.9
1430	β-copaene	t	t	-	-	-	-	-
1448	cis-muurola-3,5-diene	0.1	0.2	t	-	-	-	-
1451	trans-muurola-3,5-diene	-	-	-	-	-	-	0.1
1452	α-humulene	t	t	-	-	-	-	-
1465	cis-muurola-4,5-diene	t	0.1	-	-	-	-	0.1
1468	pinchotene acetate	-	-	-	0.8	1.4	0.5	0.6
1471	**121,105,180,208,phenol**	**0.7**	**0.3**	**0.3**	**0.7**	**1.3**	-	**-**
1471	dauca-5,8-diene	0.1	0.2	-	-	-	-	-
1475	trans-cadina-1(6),4-diene	-	-	-	-	-	-	0.3
1478	**γ-muurolene**	**0.1**	**0.2**	**-**	**0.2**	**t**	-	**0.8**
1484	germacrene D	0.2	0.3	0.2	0.2	t	-	0.3
1491	43,207,161,222, C15-OH	0.4	0.3	-	-	-	-	-
1493	trans-muurola-4(14),5-diene	-	0.2	-	0.3	t	-	0.4
1493	epi-cubebol	0.4	0.5	-	0.4	0.2	t	0.4
1500	α-muurolene	-	-	0.3	0.3	t	t	1.1
1513	**γ-cadinene**	**0.4**	**1.2**	**1.3**	**0.6**	**0.3**	**t**	**3.7**
1518	endo-1-bourbonanol	1.1	1.5	0.4	1.2	0.4	-	0.4
1521	**trans-calamenene**	**t**	**2.3**	**-**	**0.6**	**t**	**-**	**-**
1522	δ-cadinene	1.9	t	1.1	0.7	0.8	0.2	4.1
1533	trans-cadina-1,4-diene	0.1	0.1	-	-	-	-	0.1
1537	α-cadinene	0.1	0.2	t	t	-	-	0.4
1544	α-calacorene	t	t	-	-	-	-	0.3
1548	elemol	0.5	0.9	-	0.1	0.7	0.9	-
1555	**elemicin**	**1.2**	**t**	**1.5**	**0.7**	**0.5**	**-**	**-**
1559	germacrene B	t	0.1	-	-	-	-	-
1561	(E)-nerolidol	-	-	-	-	t	-	-
1574	germacrene-D-4-ol	1.6	1.1	0.7	0.8	0.4	t	0.6
1582	caryophyllene oxide	t	0.3	t	t	-	t	-
1586	gleenol	-	-	-	-	-	-	0.3

KI	Compound	grandis San Gab	grandis Big Bear	grandis Meyers	grandis Stamp	grandis Beckw.	osteo Nevada	occid McArt.
1587	trans-muurol-5-en-4-α-ol	t	t	-	-	-	-	-
1607	β-oplopenone	0.6	0.8	0.4	0.4	0.1	t	0.4
1618	1,10-di-epi-cubenol	t	t	t	-	-	-	0.2
1627	1-epi-cubenol	0.4	0.5	t	0.7	0.3	-	1.6
1630	γ-eudesmol	t	t	-	-	t	0.2	-
1638	epi-α-cadinol	0.6	0.6	0.7	0.6	0.3	t	1.1
1638	epi-α-muurolol	0.7	0.6	0.7	0.6	0.4	t	1.2
1644	α-muurolol	0.2	0.1	t	0.2	t	t	0.7
1649	β-eudesmol	0.1	0.2	0.4	t	0.2	0.2	-
1652	α-eudesmol	0.8	0.6	-	-	0.2	0.2	-
1652	α-cadinol	0.8	0.7	1.6	1.3	0.9	0.2	1.8
1675	cadalene	t	0.1	-	-	-	-	0.3
1687	43,167,81,238, unknown	0.1	0.3	-	-	-	-	-
1688	shyobunol	-	-	0.2	t	-	-	-
1739	oplopanone	0.1	0.2	t	0.2	-	t	-
1987	**manoyl oxide**	**t**	**t**	**t**	**-**	**-**	**-**	**3.2**
2009	epi-13-manoyl oxide	-	-	-	-	-	-	t
2056	manool	-	-	t	0.4	-	-	-
2055	abietatriene	-	-	t	t	-	-	-
2298	4-epi-abietal	-	-	t	0.2	-	-	-
2312	abieta-7,13-dien-3-one	-	-	-	-	-	0.2	-

Table 2. Variation in major oil components for several *J. grandis* individuals from the San Bernardino and San Gabriel Mtns. Column heading is tree # followed by SB (San Bernardino) or SG (San Gabriel Mtns.). San Gab and San Bern are population averages for San Gabriel and San Bernardino Mtns. populations. Some compounds with extreme variation are in boldface.

KI	Compounds	11993SB	13533SG	12321SB	12319SB	13535SG	San Gab	San Bern
932	**α-pinene**	**4.0**	**4.9**	**9.6**	**5.1**	**4.4**	**10.6**	**7.1**
961	verbenene	0.2	0.5	0.5	1.2	1.4	1.0	0.3
969	**sabinene**	**24.6**	**24.4**	**17.3**	**13.8**	**13.5**	**14.8**	**24.3**
974	β-pinene	0.3	0.3	0.9	0.4	0.3	0.8	0.5
988	myrcene	1.9	2.7	1.2	1.7	1.9	0.6	1.7
1002	α-phellandrene	0.2	1.3	0.2	0.4	0.4	1.2	0.4
1008	**δ-3-carene**	**0.3**	**0.4**	**0.8**	**11.5**	**17.3**	**13.4**	**2.8**
1014	**α-terpinene**	**3.5**	**6.6**	**2.9**	**2.6**	**0.1**	**4.9**	**3.0**
1024	limonene	0.8	3.2	0.3	0.6	1.2	2.8	1.6
1025	β-phellandrene	0.9	5.0	1.3	2.4	2.0	4.2	1.5
1054	γ-terpinene	5.8	5.6	5.3	4.7	3.0	4.6	4.9
1065	cis-sabinene hydrate	2.6	0.9	1.6	1.0	0.5	0.5	1.9
1086	terpinolene	1.9	3.5	1.7	2.7	2.8	3.8	1.9
1095	trans-sabinene hydrate	2.5	0.9	2.0	1.6	0.5	0.7	1.8
1174	**terpinen-4-ol**	**11.7**	**6.5**	**13.2**	**10.6**	**5.9**	**4.6**	**9.3**
1223	citronellol	t	0.4	0.3	0.1	1.8	0.6	0.2
1284	bornyl acetate	0.2	0.5	0.4	0.1	0.2	1.5	2.2
1322	**methyl geranate**	**0.8**	**1.8**	**0.9**	**0.6**	**4.6**	**1.6**	**1.8**
1513	γ-cadinene	1.2	0.3	1.1	1.6	0.3	0.4	1.2
1518	endo-1-bourbonanol	1.4	1.8	2.6	2.9	0.6	1.1	1.5
1522	δ-cadinene	1.8	2.3	2.2	2.4	1.3	1.9	t
1555	**elemicin**	**t**	**0.1**	**t**	**t**	**6.5**	**1.2**	**t**
1574	germacrene-D-4-ol	1.0	1.6	1.5	1.7	1.0	1.6	1.1
1607	β-oplopenone	0.8	0.5	1.1	1.4	0.9	0.6	0.8
1638	epi-α-cadinol	0.7	0.6	0.6	0.9	0.7	0.6	0.6
1652	α-eudesmol	0.6	0.8	0.6	1.0	1.1	0.8	0.6
1652	α-cadinol	0.7	0.8	0.7	1.1	1.2	0.8	0.7